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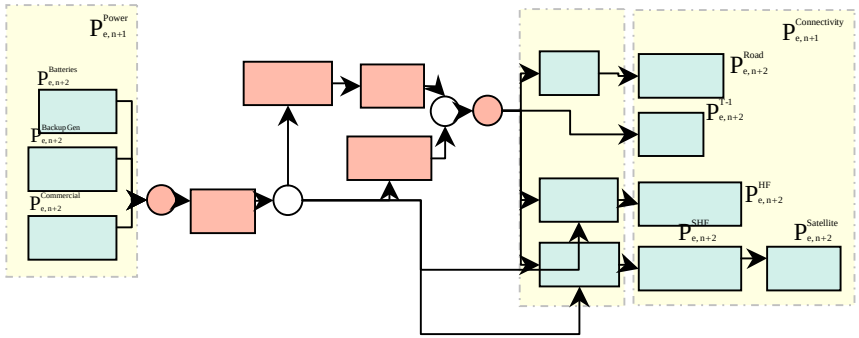

$$PE_n^{Facility} = 1 - \prod_{k=1}^{z} (1 - PE_{e,n+1}^{k})$$

An Employee-Owned Company

Probability of Effects for Systems

Marc Warburton (SAIC)
Mark Gallagher and Wesley True (USSTRATCOM)
23 June 2005

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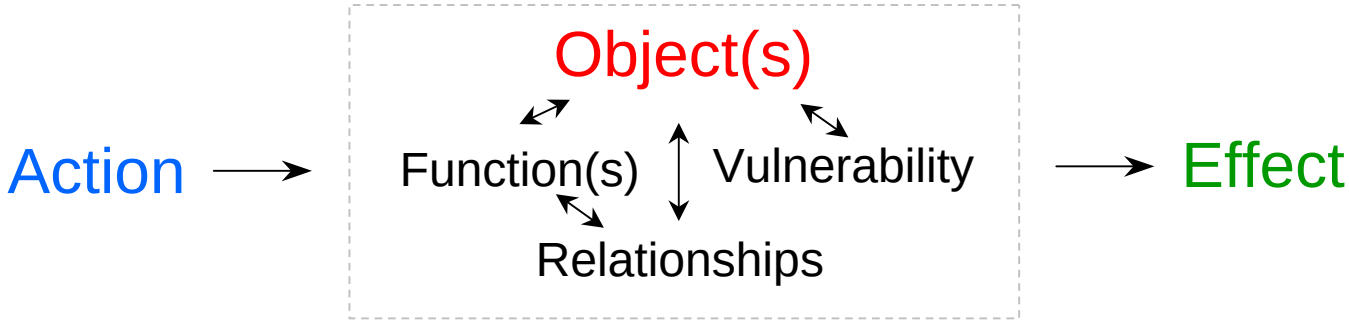
Problem

- Problem:
  - How do you calculate the probability of getting the effect you want against a system?
  - What else is important when you impose an effect?
- Why do we care?
  - We ultimately seek to compare Courses of Action (COAs)

Key Definitions



- Actions are applied to objects
- Actions modify the object's functions, thereby producing an effect
- The extent of the effect depends on the vulnerability of the object to the action
- The overall effect depends upon the physical and functional relationship of the objects, sub-objects, and their functions

Top Level Methodology

1. What do you want to accomplish?
2. Which objects are pertinent, and what do they do?
3. How are they put together?
4. How are they vulnerable to what you want to do, and to which actions?
5. What's the math?
6. What else is important besides effectiveness?
7. What are the uncertainties?

1. Specifying Desired Effects

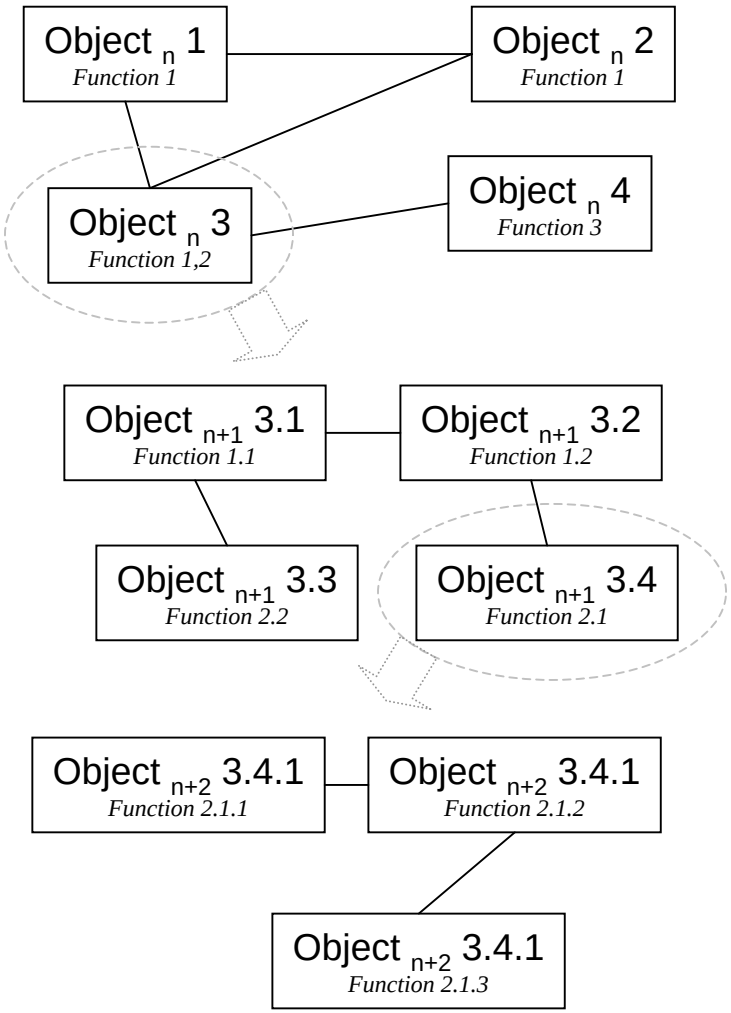
- Essentially, the commander's intent
  - Defined by his value structure[1]
- Can specify a desired effect at any level in the system
- Specify effect, not action[2]
  - The desired functional capability or behavior to impact
  - Extent (facilities or individuals) over which effect is desired
  - Extent of effect
  - Start time
  - Minimum duration
- What constraints or other evaluation metrics are important?

[1] *"Value Focused Thinking For Organizing Effects-Based Planning" Phipps and Gallagher 27 Aug 04.*

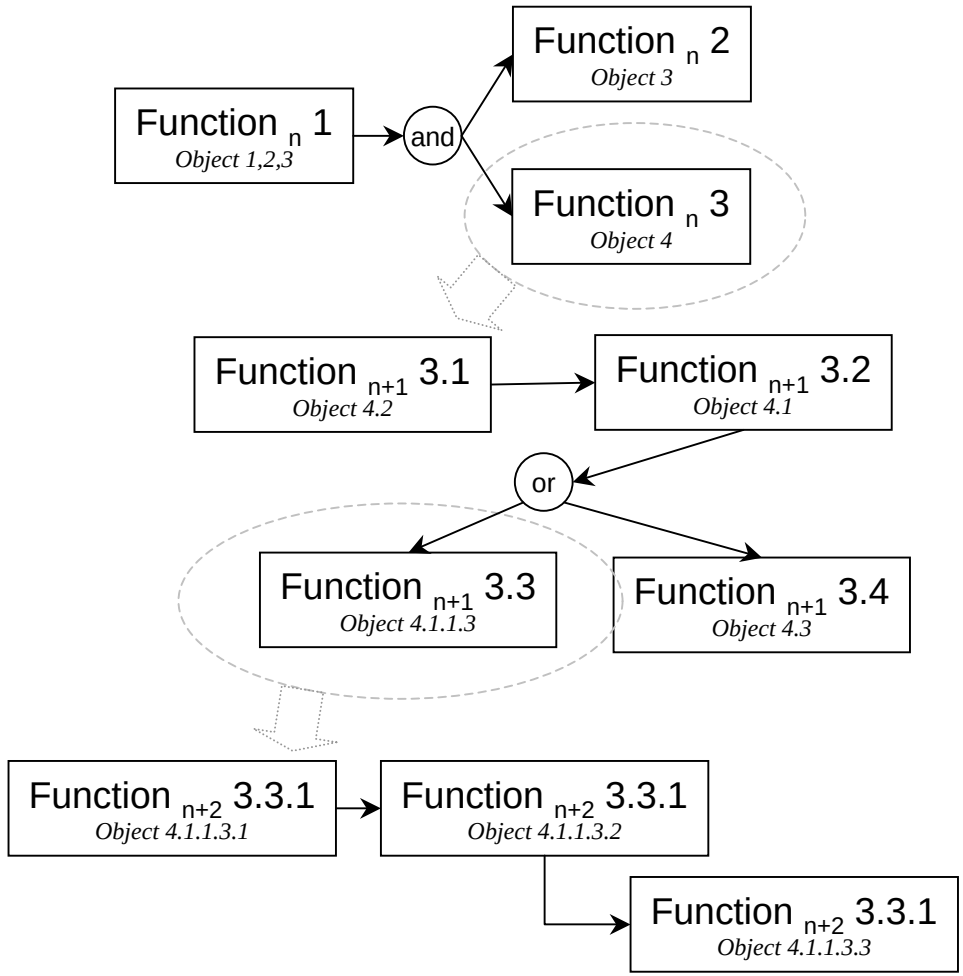
[2] *"Precisely Defining Effects for Effects-Based Operations (EBO)" Gallagher and True, 19 Aug 04.*

2. ID Pertinent Objects & What They Do

Object (Physical) View



Function View

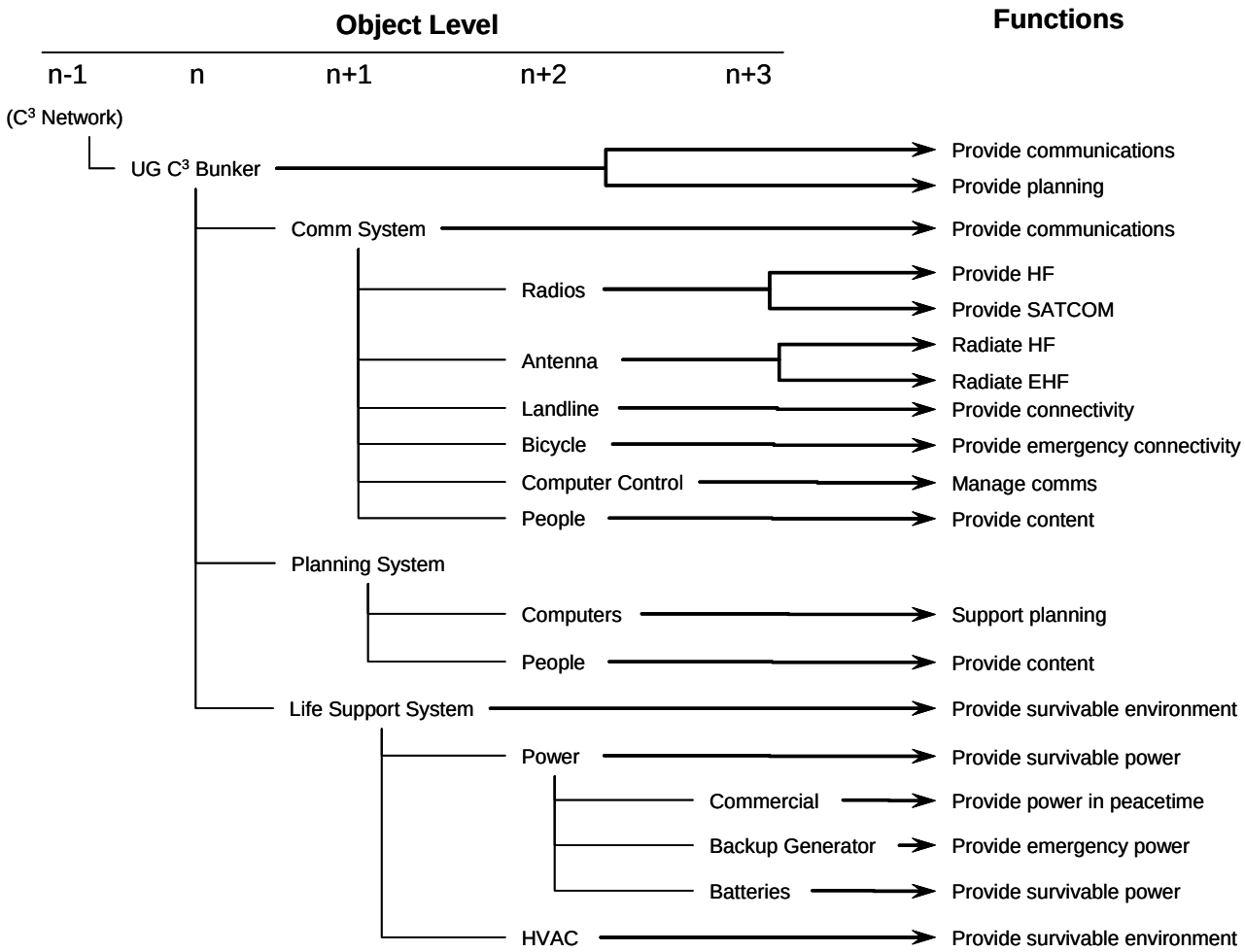


Breakdown to Targetable Object

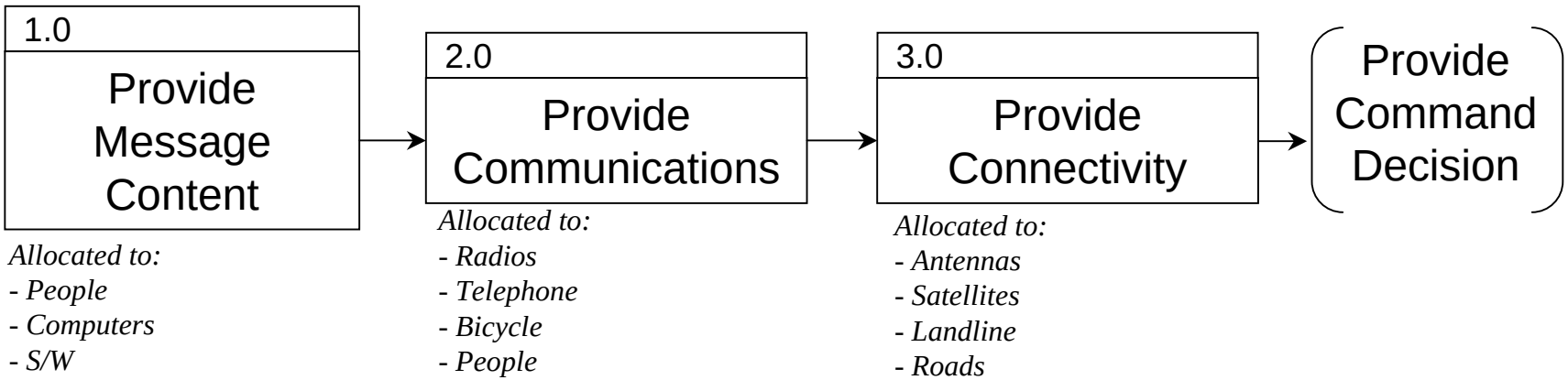
- In general, objects are comprised of subobjects
- The object at the level of an appropriate action is the “targetable object”
  - Breakdown below this level is not necessary
- Examples of different targetable objects:
  - HEMP attack on entire power net (level n)
  - Nuclear attack on C3 node (level n+1)
  - GBU 28 attack on a generator (level n+3)
  - CNA attack on a single computer file (level n+6)
- In general, more “nuanced” actions require more breakdown

We seek the functional and physical relationships between targetable objects

Example Object Diagram



Functional Analysis Mini-Example: UGC^2

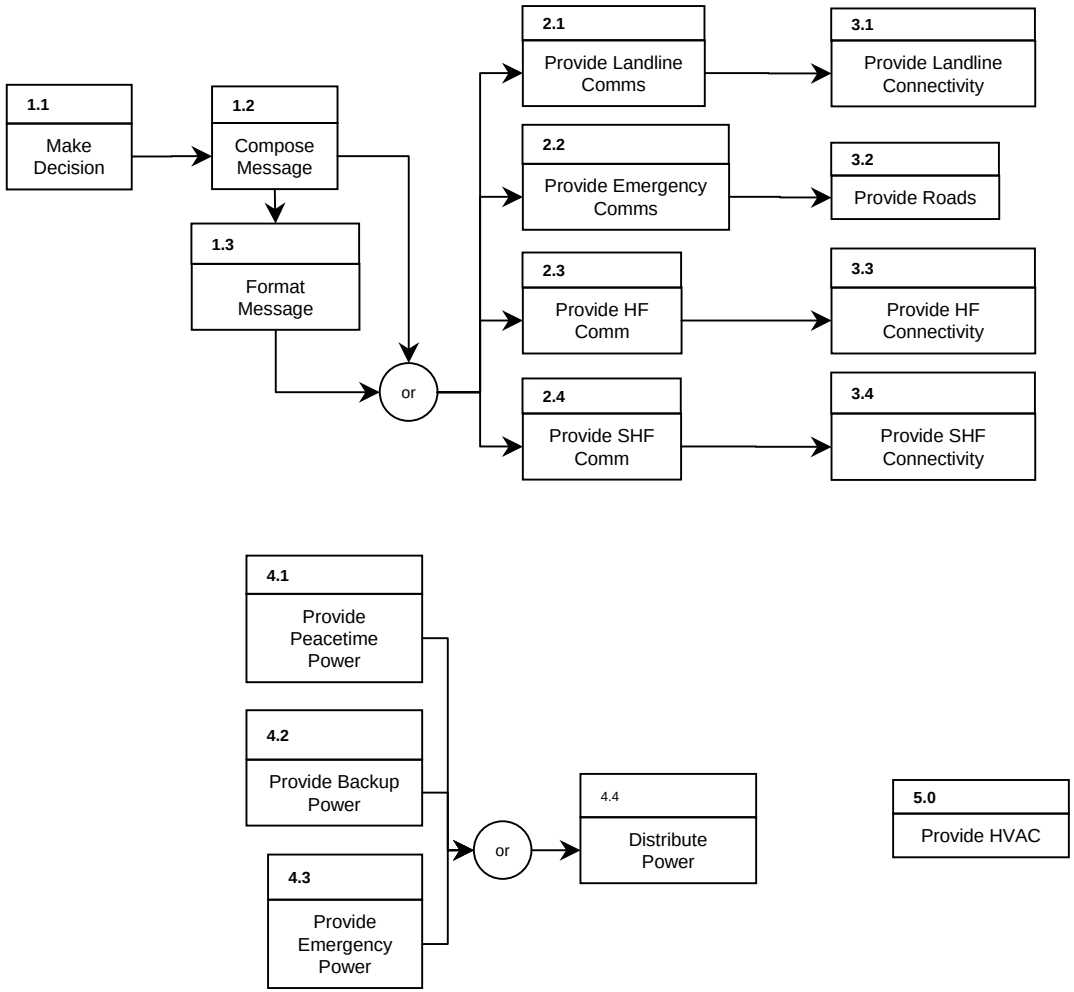


Derived Requirements:

- People: Protection, HVAC, food, water, sewer
- Computers: Protection, power
- Radios: Protection, power
- HVAC: Protection, power, water

But functional descriptions are abstract

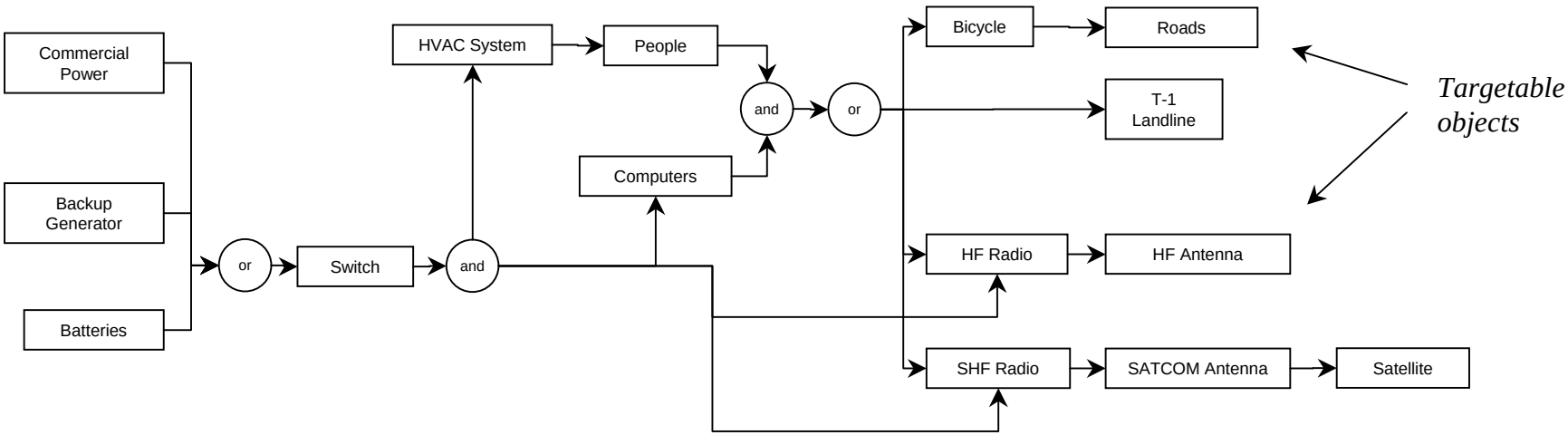
Example UGC² Functional Diagram



3. How are Objects Put Together?

Desired Effect + Functions + Object Allocations ⇒ Critical Hybrid Diagram

E.g., For a desired effect of interruption:



4. ID Object Vulnerabilities to Actions

AKA: Action-Object-Effect Linkage Analysis

"Probability of Effect"

Targetable Object	Level	Function	Desired Effect	Vulnerability	Action and Mechanism	P_e
UGC3 Facility	N	Provide command decisions	Halt decisions for >72 Hrs	Crush facility	Nuclear overpressure	$P_{e,1}$
				Destroy contents	Conventional penetrator fragmentation	$P_{e,2}$
1.0 People	N+1	Provide decisions	Halt decisions for >72 hrs	Crush	Nuclear overpressure	$P_{e,3}$
				Perforate	Conventional penetrator fragmentation	$P_{e,4}$
				Intimidate	Nearby nuclear blast	$P_{e,5}$
				Persuade	Leaflets	$P_{e,6}$
2.0 Comm System	N+1	Provide communications	Not targetable at this level			
1.1 SHF Radio	N+2	Provide high bandwidth real time communications	Halt output for >72 hours	Turn off	CNA virus attack	$P_{e,7}$
				Nuclear EMP burnout	Nuclear EMP burnout	$P_{e,8}$
1.2 Bicycle	N+2	Provide comms when all electronic means gone	Halt use for >72 hours	Area denial	Nuclear ground burst radiation	$P_{e,9}$

What is P_e at the Targetable Element Level?

- Ideally, P_e derived from a math model that includes the effect desired, vulnerability, and action mechanism
  - E.g., P_d from PDCALC or JMEM
- P_e for many action-object-effect mechanisms must be developed
- P_e must be consistent
  - P_e of an lower level effect must be consistent with the overall effect desired
  - E.g., can't include "halt for >72 hours" with "alter message content for >72 hours"

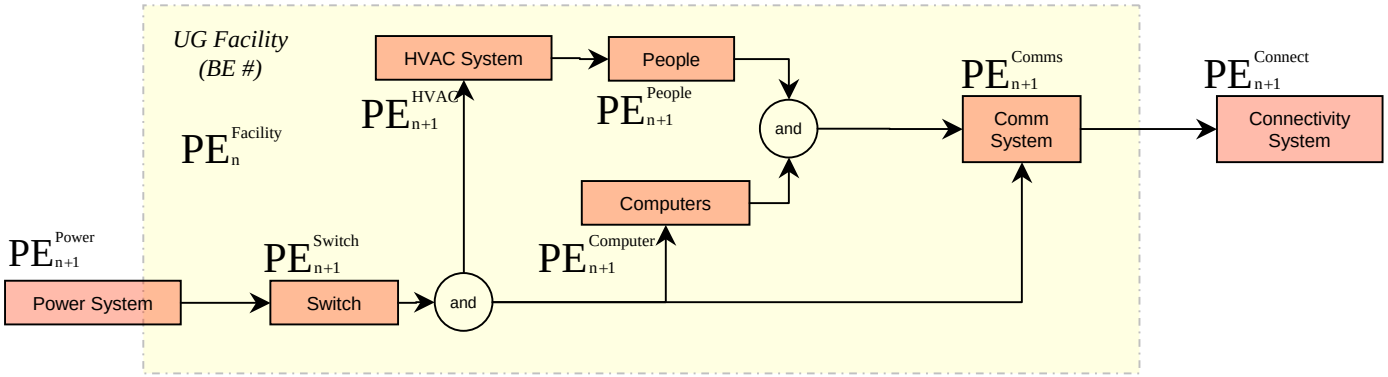
5. Determine the Math

Probability of Effect Expectancy Defined

Action → Object → Effect

Probability of Arrival (PA_n)	x	Probability of Effect ($P_{e,n}$)	=	Probability of Effect Expectancy (PE_n)

Math Example: Interrupting a UGC^2 Facility



- Stopping <u>any</u> of these n+1 level functions stops the n level facility function. Thus the Effect Expectancy at the nth level is:

$$PE_n^{Facility} = 1 - \prod_{k=1}^{z}(1 - PE_{n+1}^{k})$$

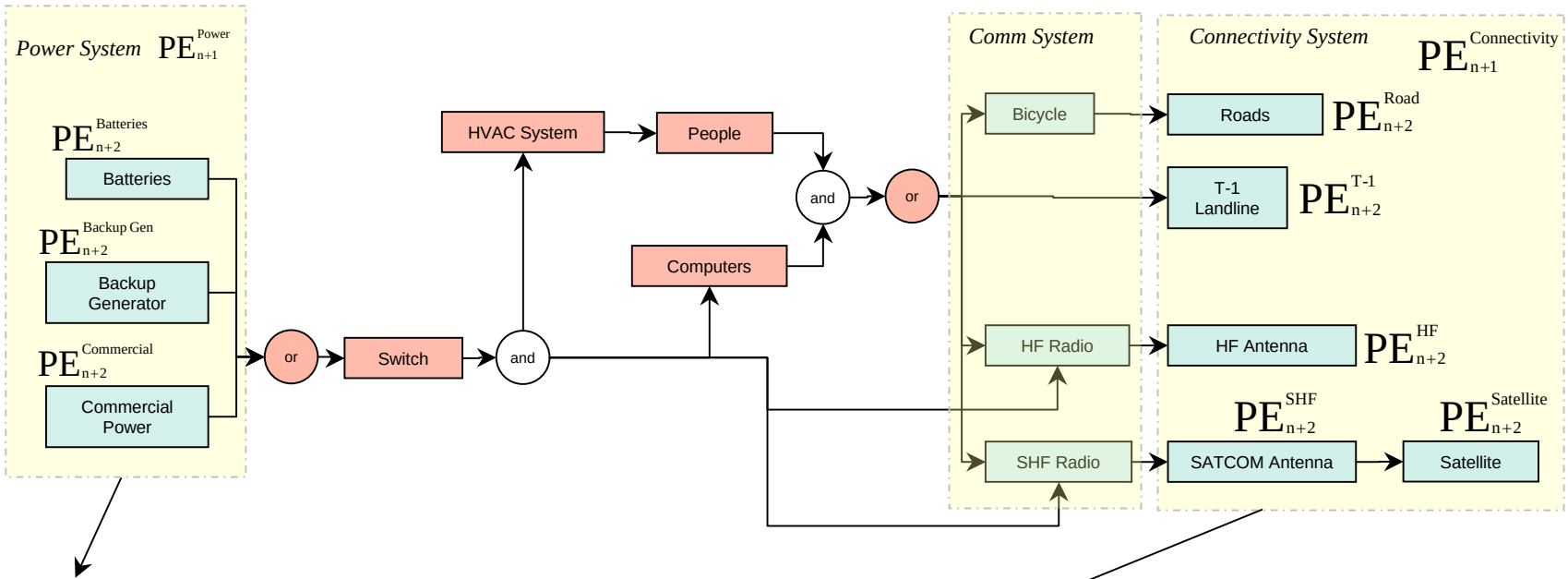
  where k refers to the attacked <u>critical path</u> objects
- However, some functions are redundant systems that are not directly targetable at the n+1 level; e.g.:
  - Power
  - Comms
  - Connectivity

The math is generalizable to other desired effects, but the hybrid diagram will probably be different

Targeting Redundant Systems

All these n+2 level objects must be addressed to affect the n+1 level function. So…..

$$PE_{n+1\,level} = \prod_{k=1}^{z} PE_{n+2\,level}^{k}$$

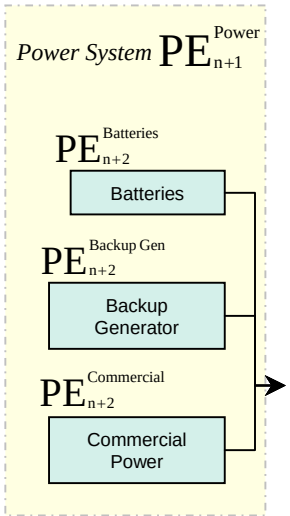


$$PE_{n+1}^{Power} = PE_{n+2}^{Baterries} \cdot PE_{n+2}^{Commercial} \cdot PE_{n+2}^{Backup\,Gen}$$

Series component in a parallel subsystem

$$PE_{n+1}^{Connectivity} = PE_{n+2}^{HF} \cdot PE_{n+2}^{Road} \cdot PE_{n+2}^{T\text{-}1} \cdot (1-[(1-PE_{n+2}^{SHF}) \cdot (1-PE_{n+2}^{Satellite})])$$

Including Intelligence Uncertainties



Power Source	Prob Used	Prob We Know Where It Is
Commercial	$P_{comm,\ used}$	$P_{comm,\ know}$
Backup gen	$P_{gen,\ used}$	$P_{gen,\ know}$
Batteries	$P_{batt,\ used}$	$P_{batt,\ know}$

Key Intelligence Collection Drivers

$$PE^{Power}_{n+1} = (1 - P_{comm,\ use}(1 - P_{comm,\ know} \cdot PE^{commercial}_{n+2})) \cdot$$

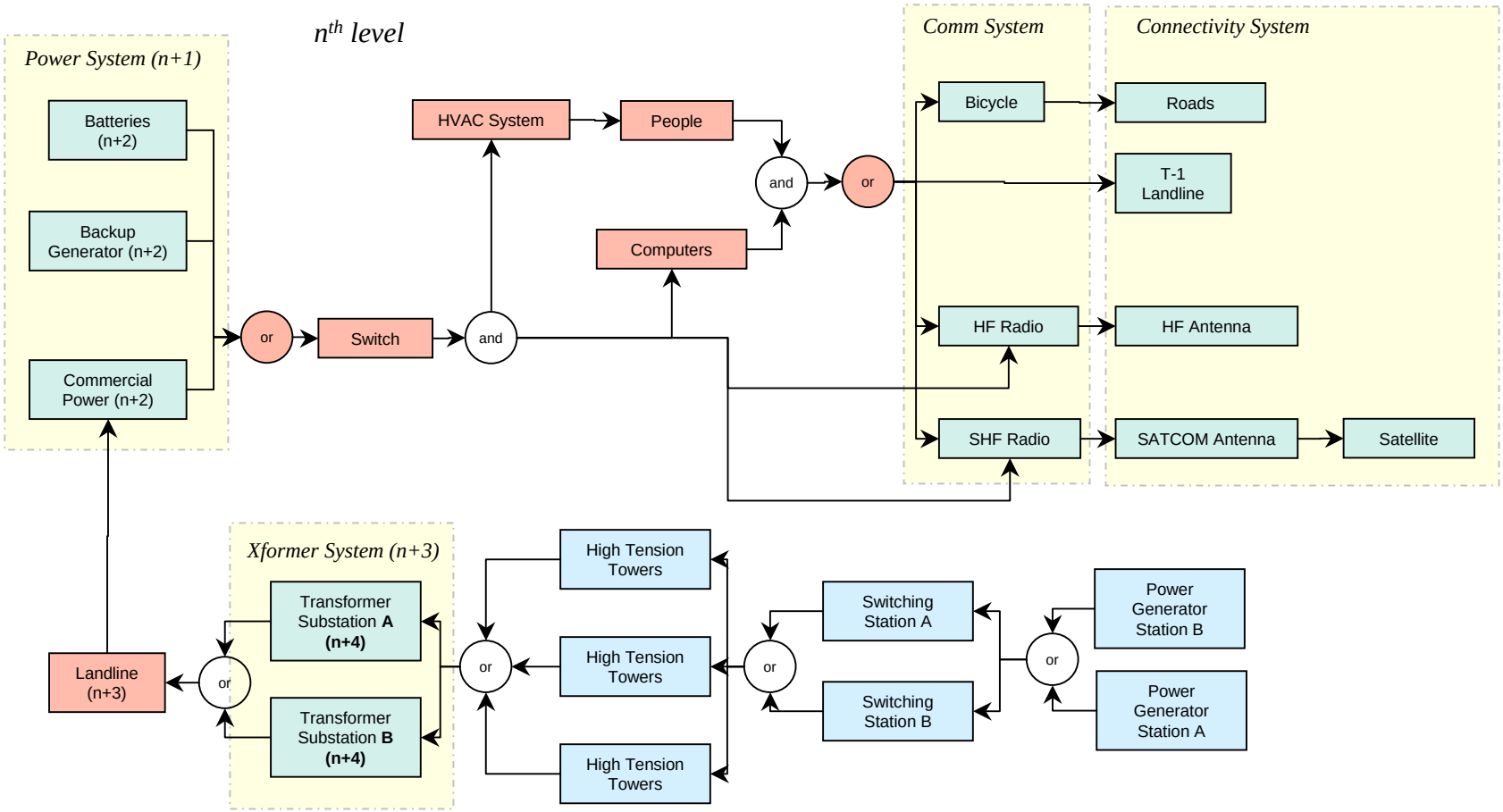
$$(1 - P_{gen,\ use}(1 - P_{gen,\ know} \cdot PE^{gen}_{n+2})) \cdot$$

$$(1 - P_{batt,\ use}(1 - P_{batt,\ know} \cdot PE^{batteries}_{n+2}))$$

Limitations

- Actions and their effects assumed to be <u>independent</u>
  - Synergy between actions not included
    - ✓ Similar to current approach when allocating multiple weapons to a target – you don't take credit for prior damage
    - ✓ Conservative assumption
- Non-parametric treatment of effectiveness
  - Does not return a function of effect vs. action
  - Must specify a different effect and recalculate P_e
    - ✓ Similar to P_d (severe damage) and P_d (moderate damage)
- Approach non-dynamic (so far)

Where Does It End….?



….at a level consistent with the targetable objects that will give the effect desired.

6. What Else is Important?

- Imposing one's will has consequences:
  - Collateral effects
  - Unintended effects
  - Costs
- These consequences are part of the COA evaluation and comparison process; they are part of the "effect"
- Which consequences are important are tied to the Commander's value structure

The Effects Array

- Introduce the Effects Array at the n^{th} level:

$\mathbf{EA_n}$ = {$P_{e,n}$, PA_n, PE_n, collateral effects, costs, other value-related issues,…..}

- Represents the probability the desired effect at the n^{th} level is obtained, and the associated consequences and/or resultant effects

Deriving the Effects Array

						Effects Vector Components						
Targetable Element (Object)	**Level**	**Function**	**Desired Effect**	**Vulnerability**	**Action and Mechanism**	**P_e**	**PA**	**Collateral Casualties**	**Air Crew Losses**	**Cost to Rebuild**	**BDA**	**Other??**
1.0 People	n+1	Provide decisions	Halt decisions for >72 hrs	Crush	Nuclear overpressure	0.99	0.9	10^3	4	10^7	9	?
				Perforate	Conventional penetrator fragmentation	0.7	0.83	0	15	0	4	?
				Intimidate	Nearby nuclear blast	0.3	1.0	0	0	0	1	?
				Persuade	Leaflets	0.1	1.0	0	5	0	1	?

Estimates derived from modeling, SMEs, WAGNERs, astrological tables, and chicken bones

- Key points:
  - ✓ The effects array is meaningful only in the context of what the desired effect is
  - ✓ You can only compare arrays that result in the same effect
  - ✓ Arrays can represent multiple (i.e., aggregated) COAs, but their components (PE_n and consequence terms) must represent that fact

7. Estimating Uncertainties

- Most measurable parameters are uncertain
- Uncertainty is closely associated with risk assessment – a key "commander's value"
- Key uncertainties:
  - Statistical uncertainty inherent in probabilistic estimates
  - Intelligence
  - Weapon system performance
  - BDA
  - Modeling errors, assumptions, limitations
- The effects vector should include an uncertainty estimate with every term; e.g.:

$$\mathbf{EA_n} = \{\underbrace{0.9 \pm 0.1}_{(PE_n)}, \underbrace{4 \pm 2}_{\text{(air crews)}}, \underbrace{10^3 \pm 10\%}_{\text{(collateral)}}, \underbrace{\$10^7 \pm 50\%}_{\text{(costs)}}, \text{etc.}\}$$

Summary

- Use VFT techniques to determine desired effects at the various levels of objects and functions, and to define other important constraints and metrics
- Use functional analyses techniques from systems engineering to analyze target systems
- Use vulnerability analysis to link effects, objects, and actions, and to derive P_e
- Use a hybrid of functional and object relationship representations to derive the “mathematical effect chain” for the effect desired
- Include all relevant effects and uncertainties into an “Effects Vector” for COA comparison